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CONTINUITY EFFECTS IN THE PERCEPTION OF SOUNDS[1]

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The paper presents the phenomenon of continuity in the preception of sounds in condition of uncomplete information. On the basis of examples of perception of sounds with gliding frequency changes interrupted by noise burst, modulated tones "damaged"in similar way, it is concluded that under specific conditions the hearing system is able to restore the original sound patterns. Other examples of continuity are also given, especially, of alternating tone sequences which demonstrate that perception is not a possive process but a highly active one.

W pracy poruszono problem ciągłości i percepcji dźwięków w przypadku braków w dopływie informacji. Podano przykłady od efektów ciągłości przy percepcji zmian częstotliwościowych przerywanych wysokopasmowym szumem do ciągów impulsów tonu o różnym czasie trwania maskowanym pobodźcowo szumem. W ogólności ciągłość jest zachowana, jeśli widmo dźwięku, który ma być słyszany jako ciągły, jest pokryte widmem szumu. Przedstawione przykłady ilustrują zdolność „restoracyjną" słuchu i wskazują na rolę wyższych ośrodków neuronowych w realizacji tej funkcji. Wynika stąd, że organ słuchu demonstruje właściwości percepcyjne wskazujące na działanie nie tylko biernego , lecz również aktywnego procesu przetwarzania i „uzupełniania" informacji.

It seems to me that there is a large gap between our psycho-acoustical knowledge and that of the perception of music. We know much more about the ear's frequency resolution, the pitch-extraction mechanism, etc., than 30 years ago, but there are still musically highly relevant phenomena which need more attention from the researchers. This holds particularly for the temporal factor in tone perception. We are able to hear the individual voices in a musical performance without realizing that these voices were seemingly intermingled inextricably in the air.

This capacity of "pattern recognition" is not specific, but is a general property of our sense organs. It has had obtained much more attention in vision than in hearing. Figure 1 illustrates how visual elements are ordered in our perception on the basis of their properties and spatial relations. In Gestalt psychology laws have been

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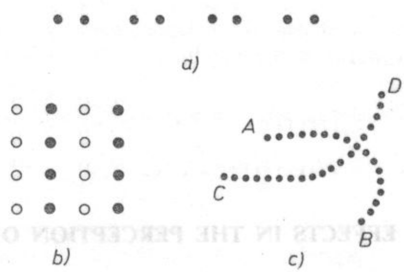

Fig. 1. Illustrations of the Gestalt principles of (a) proximity, (b) similarity and (c) good continuation (from Deutsch [4])

formulated which can explain the ordering or grouping of complex stimuli: a = proximity, b = similarity, c = good continuation, whereas d = common fate, meaning that elements which move in the same direction are perceived together (not illustrated).

A very interesting example is the case of overlapping objects. In Fig. 2a we are unable to see more than a collection of differently shaped elements, but by introducing another object (Fig. 2b) the B's become visible. This example is highly relevant in auditory perception. Due to other, masking, sounds, we may hear only fragments of a voice, but we still perceive a continuous voice signal. Apparently, the ear is able to restore that voice.

This effect can be illustrated strikingly by making use of alternating presentation of tone bursts and noise bursts. Figure 3 represents these signals. Tone bursts of a continuously varying frequency from 500 to 2000 Hz are alternated with a band of noise between 900 and 1100 Hz. As long as the frequency of the tone is below about 900 Hz or above about 1100 Hz, we hear a series of tone bursts which increase step by step in pitch. Between 900 and 1100 Hz, however, the auditory sensation is quite

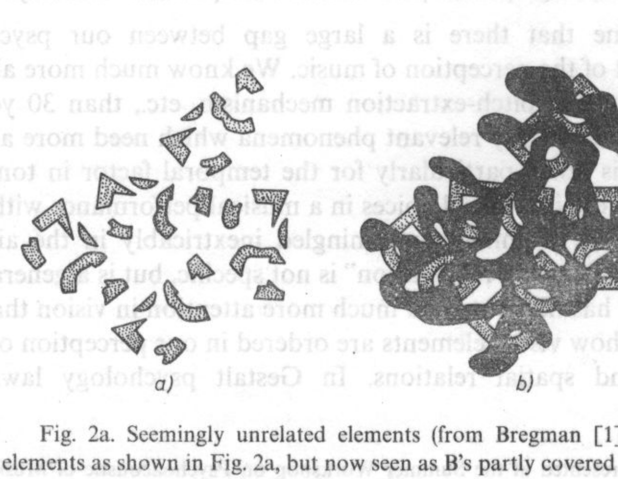

Fig. 2a. Seemingly unrelated elements (from Bregman [1])
Fig. 2b. The same elements as shown in Fig. 2a, but now seen as B's partly covered by a black object (from Bregman [1])

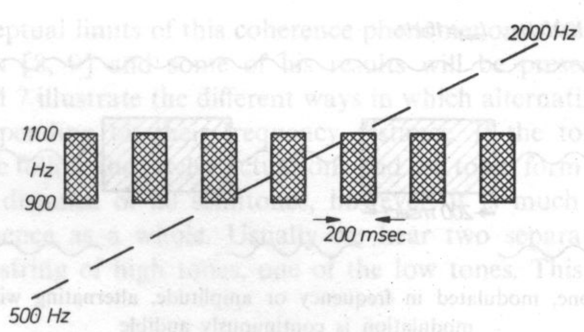

Fig. 3. Tone bursts alternating with noise bursts (noise band 900–1100 Hz). The tone bursts are heard separately for frequencies outside the noise band, but as a continuous tone for frequencies covered by this band

different: The tone is heard without interruptions and with a *continuously* increasing pitch. The effect of the noise bursts is quite different from that of silent gaps between the tone bursts: The noise bursts *connect* the tone bursts into one continuous tone.

The continuity effect seems to have been discovered independently by a number of investigators (MILLER and LICKLIDER [7], THURLOW [12], WARREN et AL., [13], HOUTGAST [5]). It only occurs when the sound spectrum of the signal to be heard continuously is completely "covered" by the spectrum of the noise (for a more correct formulation, see WARREN et AL., [13], HOUTGAST [5]). The maximum signal level at which it still sounds continuously, the pulsation threshold, has proved to be a powerful new measure in auditory research (e.g. HOUTGAST [6]).

An interesting point is: Up to what duration of the noise bursts is the impression of continuity of a tone maintained? This question was investigated by DANNENBRING [2] with alternately rising and falling, or zigzag, frequency glides centred at 1000 Hz. Halfway along a frequency glide taking 2 sec a noise burst of up to 450 milliseconds may be inserted, before the perceived continuity has gone. This value reduces to about 350 milliseconds for a steady-state tone, but increases to 650 milliseconds if the noise bursts are located at the extreme values of the frequency zigzags. These results suggest that the continuity effect of a tone is intensified rather than reduced by varying its frequency.

A tone does not need to be constant in order for the bursts to be heard as a continuous tone. Figure 4 illustrates the case of a frequency-modulated tone alternating with either noise bursts or silent gaps. The difference is large: The modulation is not very distinct when the tone bursts alternate with silent intervals, but becomes very prominent and *continuously* audible when they alternate with noise. This also holds for amplitude-modulated tones.

Repetition of the same signal is not essential for the continuity effect. When a tone burst of 40 milliseconds is immediately followed by a 300 millisecond noise burst, we hear a much longer tone burst, as if it were present during the noise. This can be demonstrated nicely by playing a scale of eight tones, half of which last 300

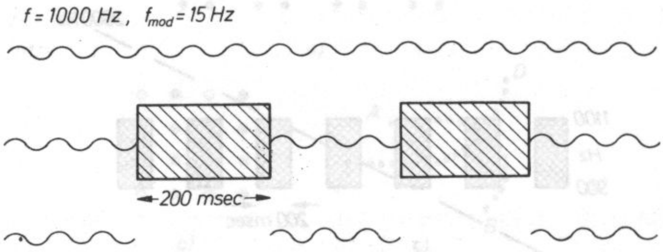

Fig 4. Bursts of a tone, modulated in frequency or amplitude, alternating with noise bursts. The modulation is continuously audible

milliseconds, the other half lasting 40 milliseconds, followed by 260 milliseconds of noise, see Fig. 5. We hear a scale of equal-duration tones, with four interfering noise bursts, not the alternation of long and short tone bursts actually presented. The implications of this effect for the perception of simultaneous notes in music were studied by RASCH [10, 11].

We may conclude from these examples that the hearing system is able to restore sound patterns if the duration of the masked portions does not exceed a few hundreds of milliseconds. The finding that the continuity effect is also operative for sounds varying substantially in time indicates that the phenomenon cannot be explained by peripheral auditory processes, but that central processes are involved. The hearing system tries continuously to restore partly "damaged" sound signals in order to give the most probable representation of our acoustical environment. In this restoration process both more innate Gestalt laws and recognition on the basis of earlier experience play a role.

Another example of continuity is to be found in tone sequences. Successive tones give a much stronger melodic coherence if their frequency distance is small than if it

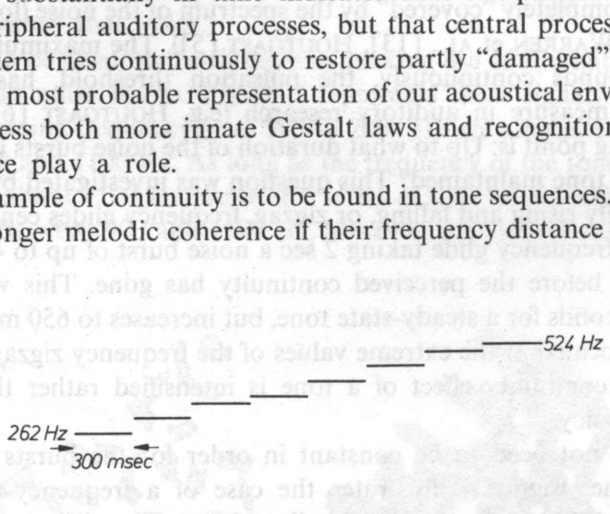

Fig. Scale of eight tones, half of them shortened from 300 to 40 milliseconds, with noise added. We hear a scale of equal–duration tones is large. The perceptual limits of this coherence phenomenon were recently explored by VAN NOORDEN [8, 9] and some of his results will be presented here.

Figures 6 and 7 illustrate the different ways in which alternating tone sequences are perceived, depending on their frequency distance. If the tones are only one semitone apart, we follow the pitch fluctuations and the tones form a coherent whole. For a frequency distance of 20 semitones, however, it is much more difficult to perceive the sequence as a whole. Usually we hear two separate sequences, one consisting of the string of high tones, one of the low tones. This is an example of fission.

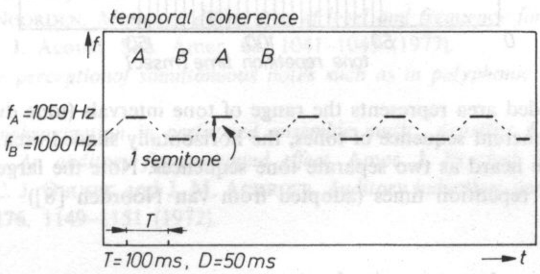

Fig. 6. Alternation of tones with a frequency difference of one semitone. The tone are perceived as a coherent sequence of tones (from VAN NOORDEN [8])

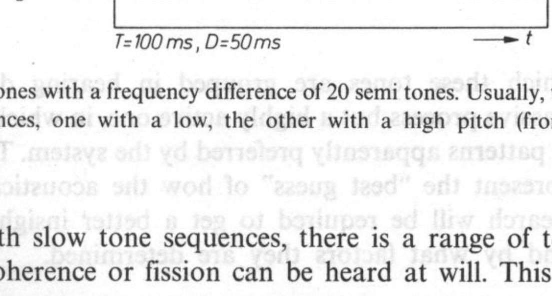

Fig. 7. Alternation of tones with a frequency difference of 20 semi tones. Usually, the tones are perceived as two separate sequences, one with a low, the other with a high pitch (from VAN NOORDEN [8])

Especially with slow tone sequences, there is a range of tone intervals where either temporal coherence or fission can be heard at will. This overlap is given in Fig. 8.

Counterpoint theory advises against crossing voices, see Fig. 9. It is indeed difficult to follow a tone sequence through a cross-over; the arrows indicate what is normally heard. This grouping tendency is so strong that even if the subsequent tones are alternately presented in the right ear and the left ear, we still hear a lower and higher melody (DEUTSCH [3]).

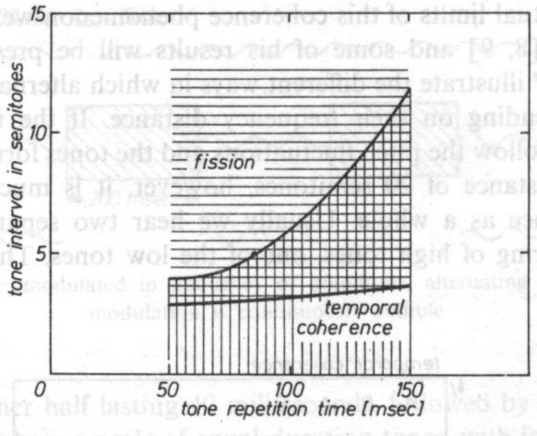

Fig. 8. The vertically shaded area represents the range of tone intervals (tone duration 40 milliseconds) that can be heard as a coherent sequence of tones, the horizontally shaded area represents the range of tone intervals that can be heard as two separate tone sequences. Note the large overlap for the longer repetition times (adopted from van Noorden [8])

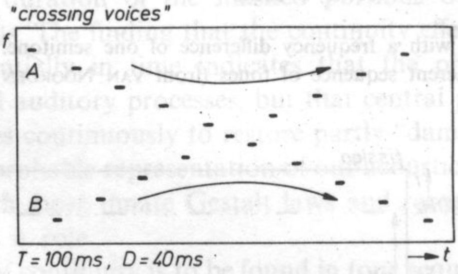

Fig. 9. The case of crossing voices. Usually the two sequences are not heard as crossing each other, but as is indicated by the arrows (VAN NOORDEN [8])

The way in which these tones are grouped in hearing demonstrates that perception is not a passive process but a highly active one, in which the elements are ordered according to patterns apparently preferred by the system. These patterns can be considered to represent the "best guess" of how the acoustical outer world is organized. More research will be required to get a better insight into how these guesses are made and by what factors they are determined.

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